Section 6

Hyperion Grating Imaging Spectrometer

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Outline

- ***Driving Requirements***
- ***Design Overview***
- ***Performance Requirements***
- ***Calibration/Characterization***
- ***Flight Validation***

Hyperion Driving Requirements

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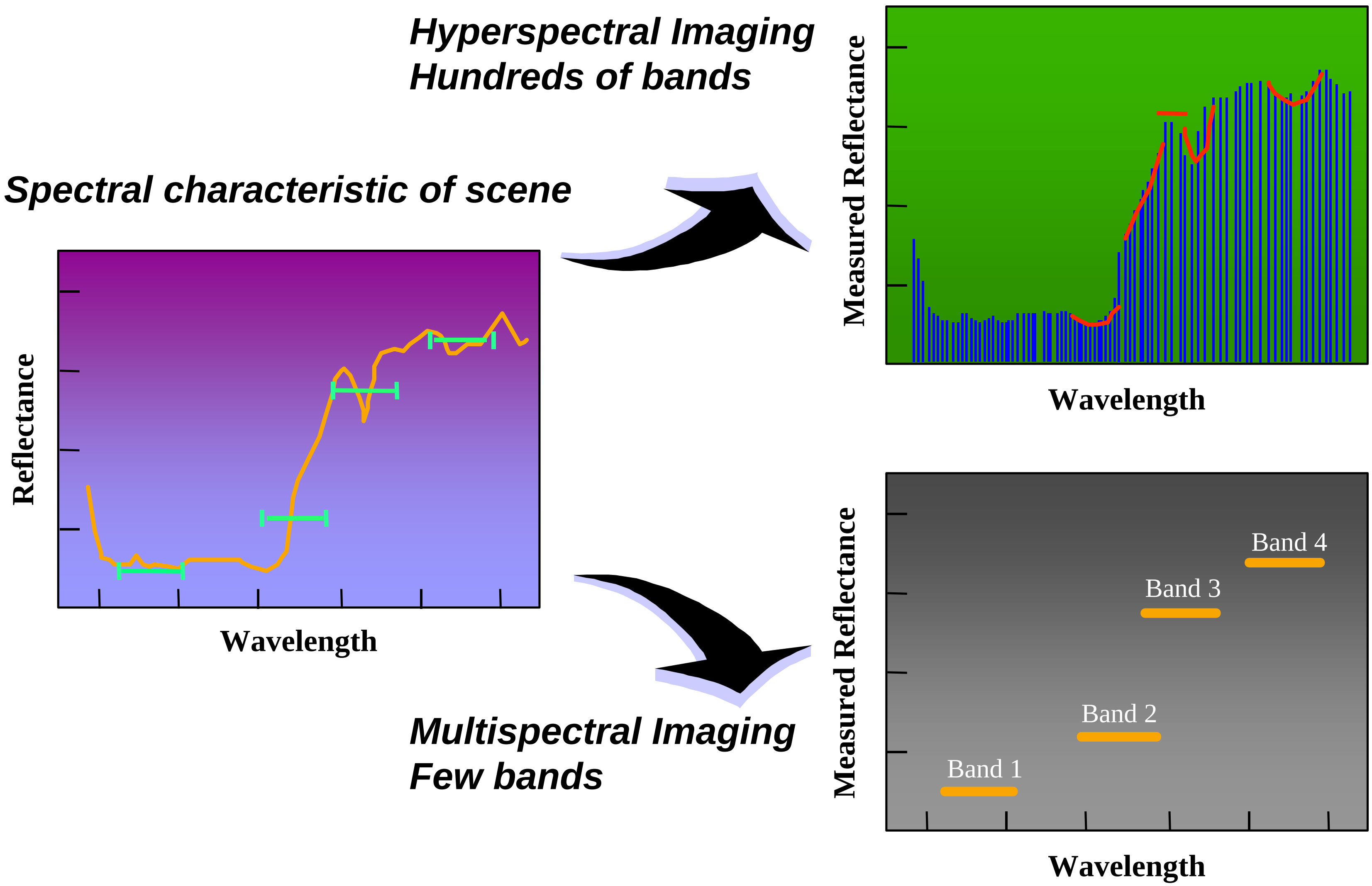
Purpose of Hyperion on EO-1

- ***Hyperion is the first hyperspectral imager in space, demonstrating this new technology***
  - *Hyperion will set the standard for hyperspectral imagery, enabling NASA to establish minimum requirements for future data buy*
- ***Hyperion FOV is coaligned with ALI's active area to enable cross-calibration of earth scenes with complete spectrum***
  - *Discrete channels on Landsat and ALI can be checked with Hyperion*
  - *Comparison with Terra MODIS and ASTER also planned*
- ***Hyperion satisfies NASA's desire to replace the Hyper-Spectral Imager (HSI) that was lost with the Lewis mission.***
  - *This new technology can provide unique insight into many scientific and commercial disciplines*

Hyperspectral Imaging Applications & Benefits

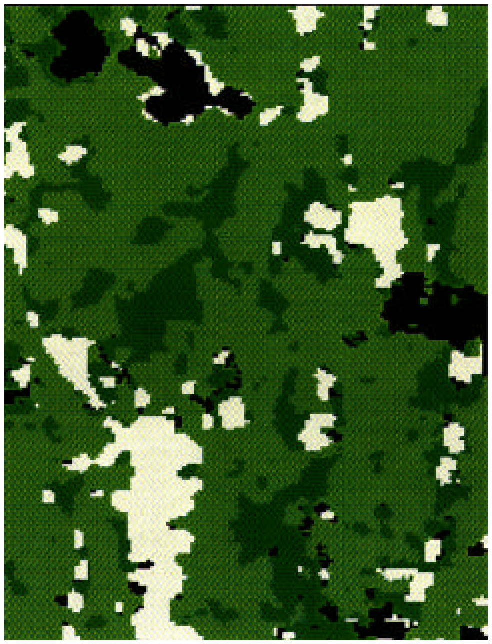
Application	Existing Satellite Capabilities (SPOT, LandSat)	Hyperion Capability	Perceived Benefits
Mining/Geology	Land cover classification	Detailed mineral mapping	Accurate remote mineral exploration
Forestry	Land cover classification	Species ID Detail stand mapping Foliar chemistry Tree stress	Forest health/infestations Forest productivity/yield analysis Forest inventory/harvest planning
Agriculture	Land cover classification Limited crop mapping Soil mapping	Crop differentiation Crop stress	Yield prediction/commodities crop health/vigor
Environmental Management	Resource meeting Land use monitoring	Chemical/mineral mapping & analysis	Contaminant Mapping Vegetation Stress

Hyperspectral and Multispectral Scene Characterization



Hyperspectral Image Provides Forestry Detail

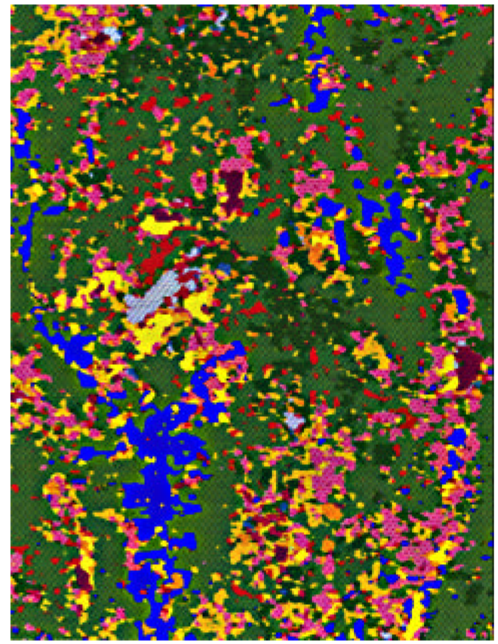
LandSat Analysis



Legend

- No Data
- Hardwood
- Softwood
- Grass / Fields

Hyperspectral Analysis



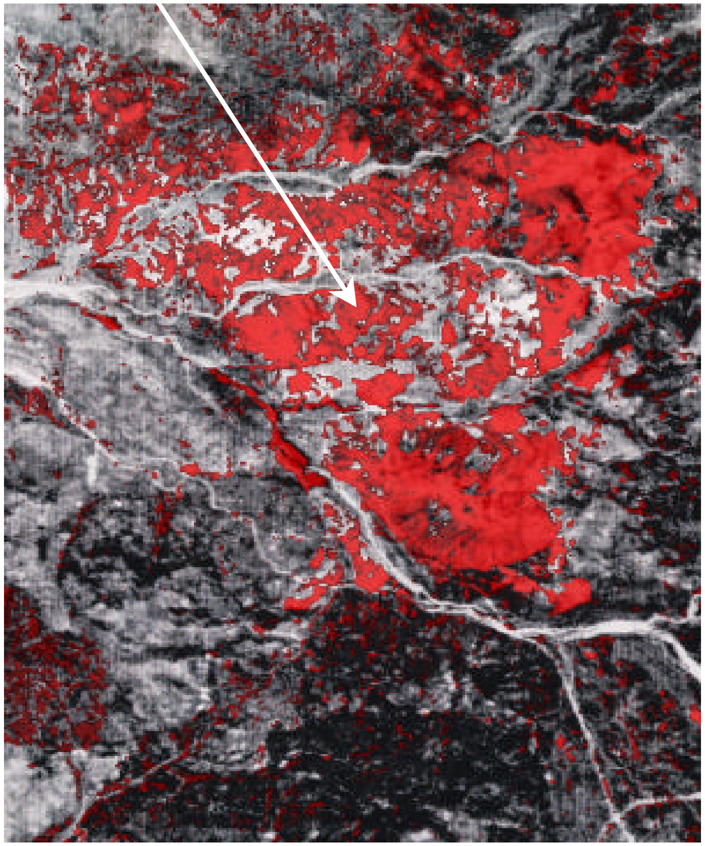
Legend

- No Data Open field
- Red Maple
- Red Oak
- Mixed Hardwood
- Hardwood/ Conifer Mix
- White Pine
- Hemlock/ Hardwood Mix
- Mixed Conifer
- Norway Spruce
- Red Pine
- Spruce Swamp
- Hardwood Bog

Analysis by Mary Martin University of New Hampshire

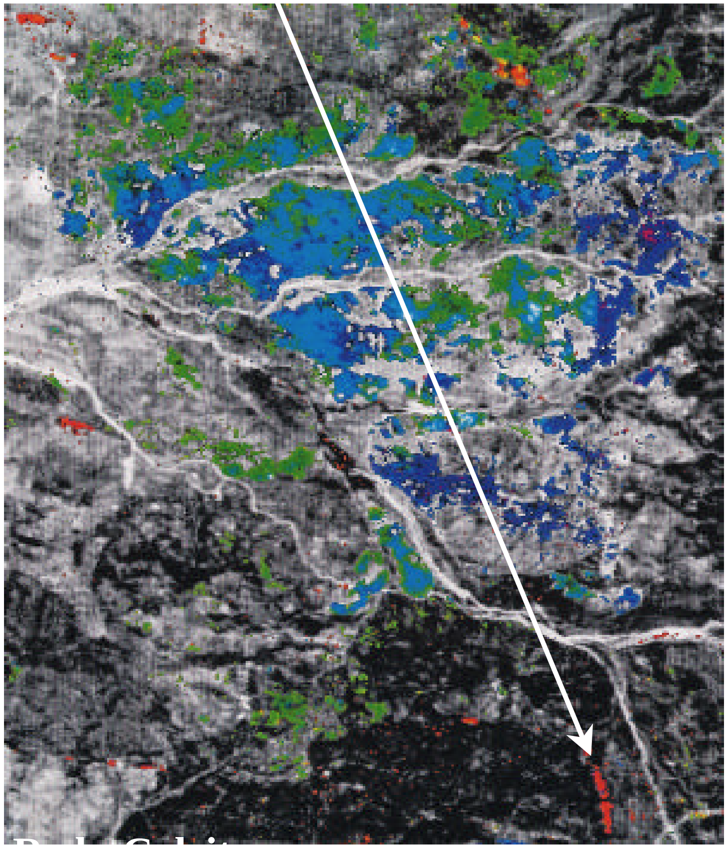
Hyperspectral Image Provides Geological Data

GEOTHERMAL AREA
(no specific mineral information)



MULTISPECTRAL ANALYSIS

CALCITE
(gold bearing quartz)



HYPERSPECTRAL ANALYSIS

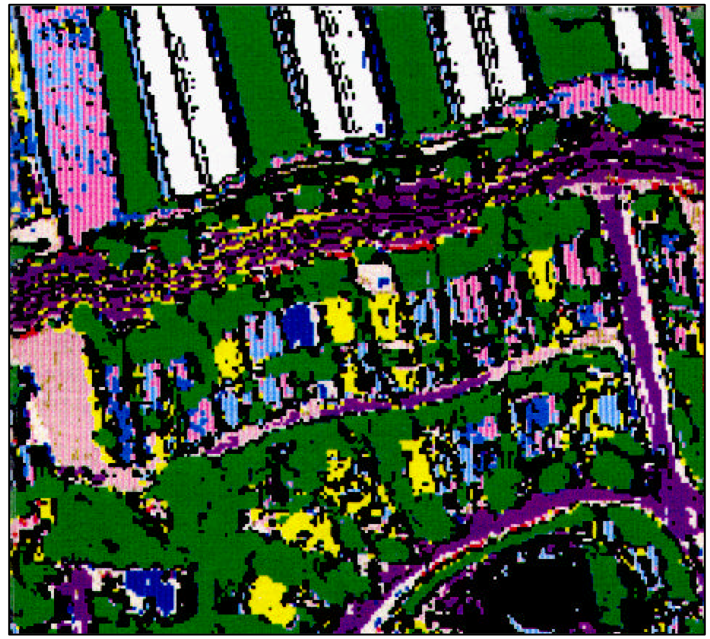
Analysis courtesy AIG Limited Liability Company

Roof Analysis and Mapping Project - Redondo Beach Middle Schools

Objective: Provide detailed map of roof composition clusters for Redondo Beach, CA fire department

Aerial Photo

Roof Composition Analysis Using Hyperspectral Data

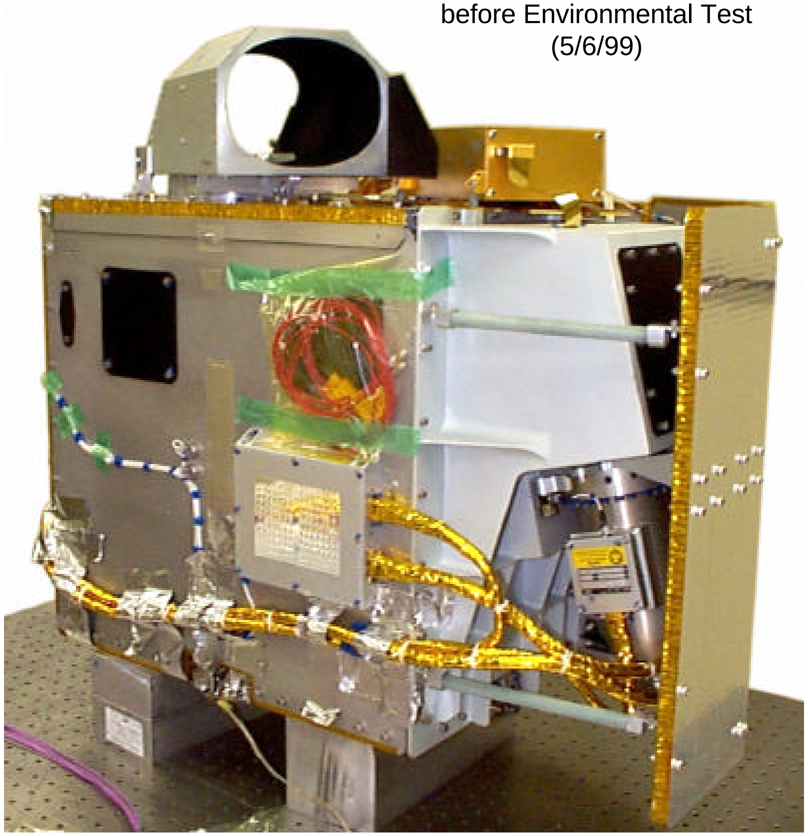


Asphalt 1	Wood
Asphalt 2	Tile
Asphalt 3	

Hyperion Hyperspectral Imager

- *Hyperion is a push-broom imager with:*
  - *220 10 nm bands covering the spectrum from 0.4 mm - 2.5 mm*
  - *6% absolute radiometric accuracy*
  - *Image swath width of 7.5 km*
  - *IFOV of 42.5 mrad*
  - *GSD of 30 m at 705 km altitude*
  - *12-bit image data*
  - *MTF 0.34 - 0.48*
  - *Power: 51W orbit avg., 126W peak*
  - *Mass: 49 kg*

Hyperion Sensor Assembly
before Environmental Test
(5/6/99)



Hyperion
12 months from order to delivery

Hyperion Origins

- *Following contract termination of planned Grating Imaging Spectrometer (GIS) and Wedge Imaging Spectrometer (WIS) due to technical problems, TRW offered to build Hyperion, a hyperspectral GIS integrated with the Advanced Land Imager (ALI), to be assembled from Lewis Hyperspectral Imager (HSI) spares and delivered to EO-1 in just 12 months*
- *Hyperion instrument redefined in first week of project as a stand-alone instrument to simplify EO-1 integration by eliminating integration with ALI*
  - *Added foreoptics and structure design based on spares from the Electro Optical Camera (EOC), another TRW instrument program*
  - *Schedule remained 12 months to delivery*
- *Even with a tight one-year schedule, the EO-1 quality requirements and technical design reviews were fully incorporated into the Hyperion program*

Hyperion Master Schedule

Even though Hyperion was an extremely fast-paced program, the parts selection and design standards were not compromised. Hyperion met the GSFC/EO-1 program quality requirements, including numerous reviews.

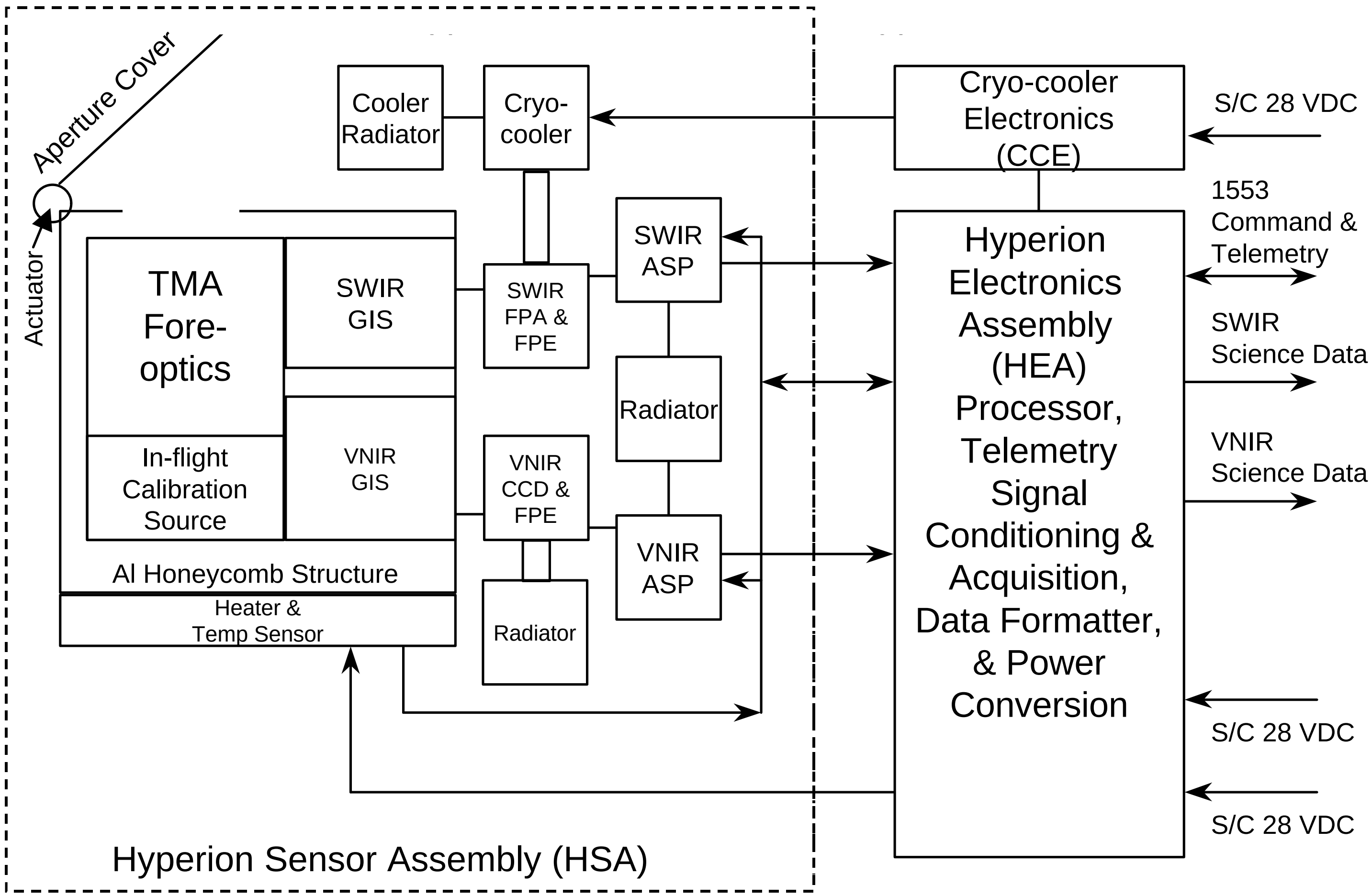
Key System Trades & Critical Analyses

- ***Dichroic Beam Splitter Vs. Dual Blazed Grating***
  - *Selected Dichroic separation of VNIR and SWIR requiring two gratings, improving performance over dual blazed grating*
- ***Instrument Spectral Bandwidth***
  - *Trade to maximize signal-to-noise ratio by optimizing the 10nm spectral width and the number of channels*
- ***Thermal Control of Opto-Mechanical Structure***
  - *Moved heaters from outside of honeycomb enclosure to the OMS structure inside honeycomb enclosure to save heater power.*
- ***1553 / 1773 Conversion***
  - *Selected transceiverless 1553 chip that matched input to EO-1 1773 fiber optic device, avoiding significant expense of developing a separate converter*

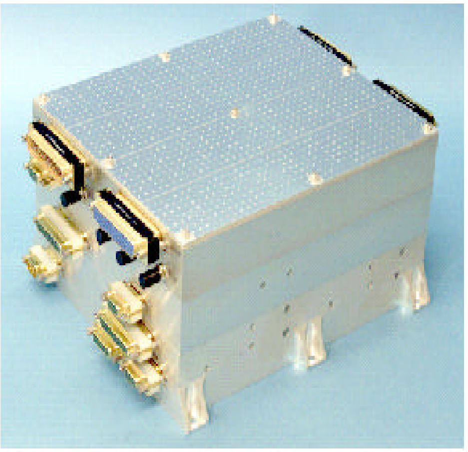
Hyperion Design Overview

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

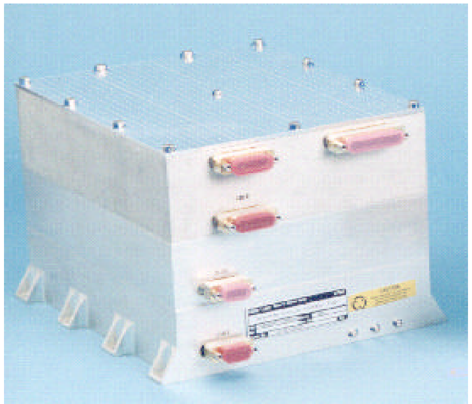
Hyperion Functional Block Diagram



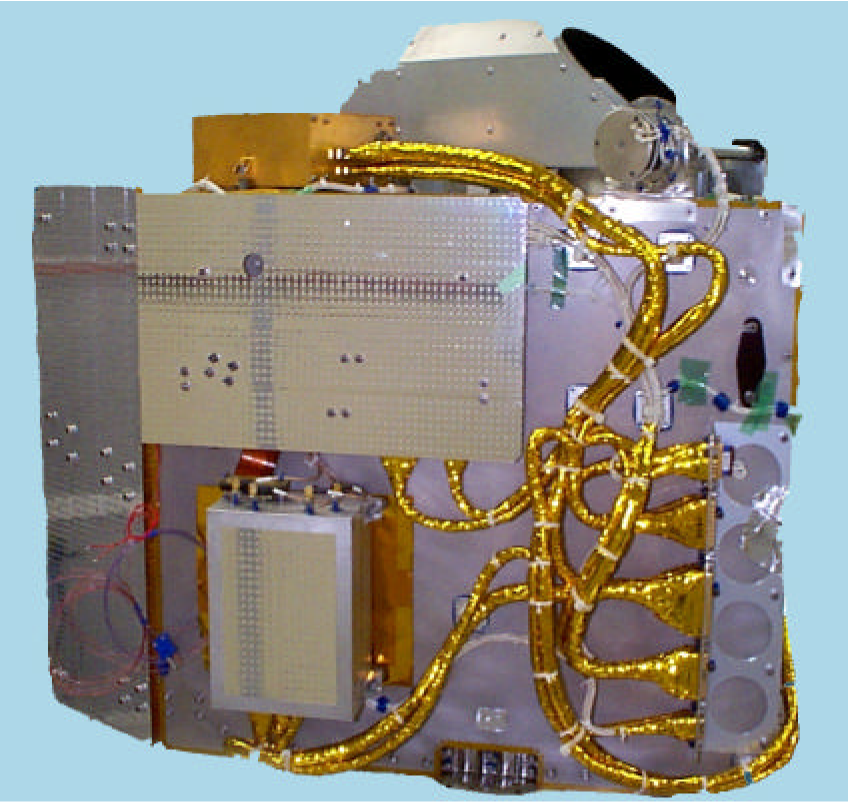
Hyperion Subassemblies



Hyperion Electronics Assembly (HEA)



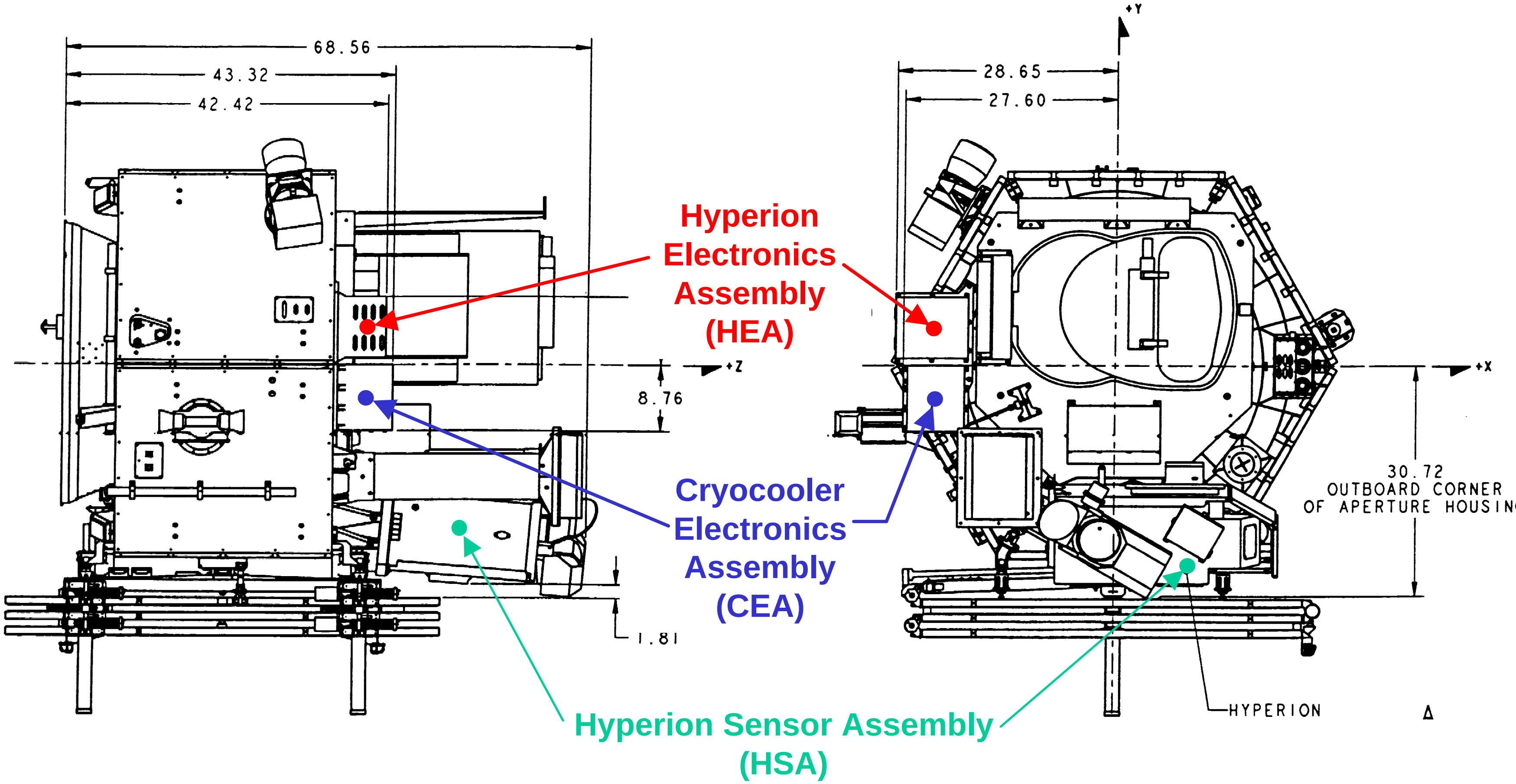
Cryocooler Electronics Assembly (CEA)



Hyperion Sensor Assembly (HSA)

Hyperion Spacecraft Accommodation

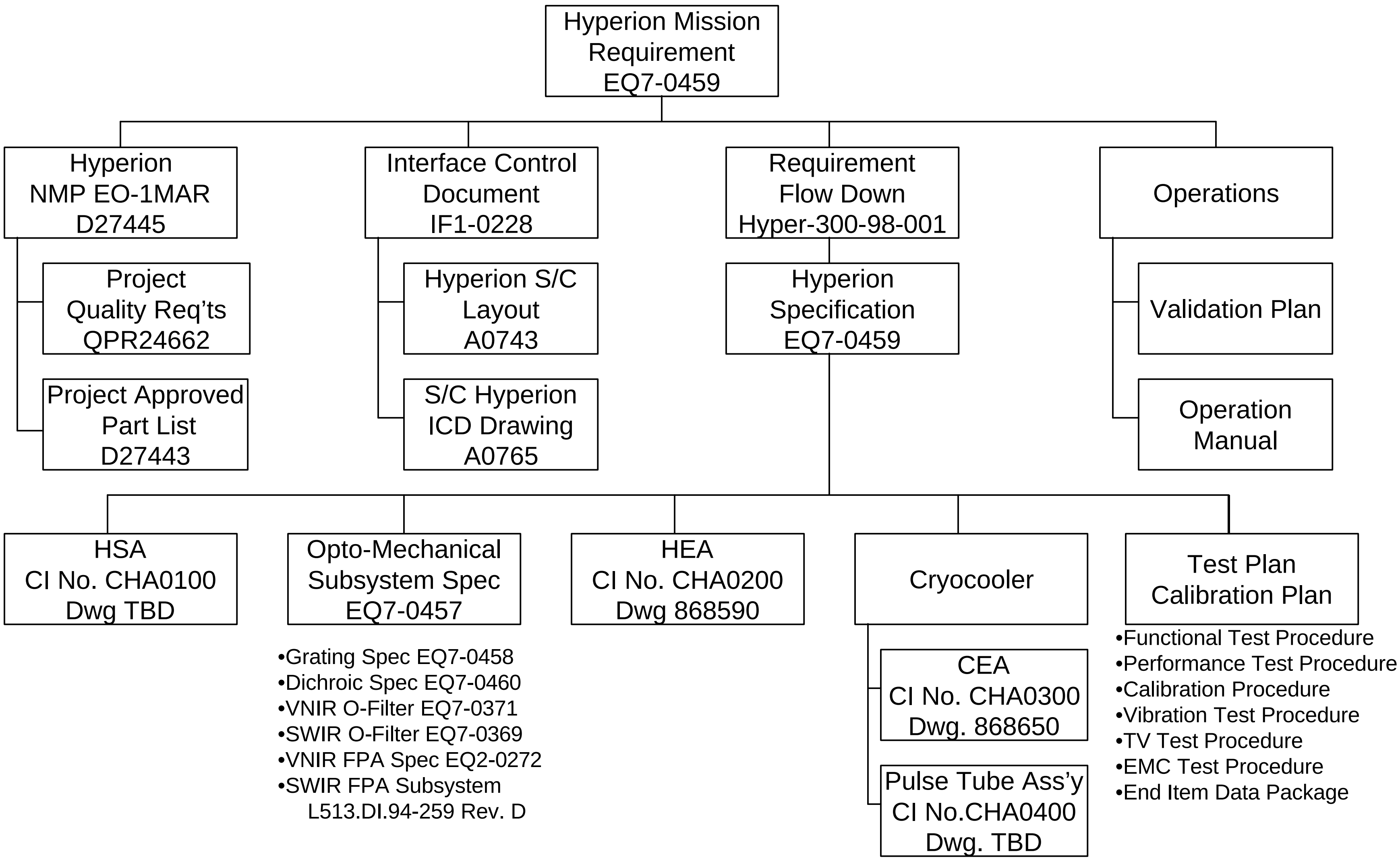
HSA, HEA and CEA locations on the EO-1 nadir deck



Hyperion Performance Requirements

. . . Steve Carman
Hyperion Project Manager
TRW Space & Electronics

Hyperion Requirements Flowdown



Hyperion Performance Requirements

Instrument Parameter	Requirement
GSD at 705 km Altitude	30 +/- 1 m
Swath Width (km)	7.5 km minimum
Spectral Coverage	0.4 - 2.5 μm
Imaging Aperture	12.5 +/- 0.1 cm diameter
On-orbit Life	1 year (2 years goal)
Instantaneous Field of View	42.5 +/- 3.0 μrad
Number of Spectral Channels	220 minimum
SWIR Spectral Bandwidth	10 +/- 0.1 nm
VNIR Spectral Bandwidth	10 +/- 0.1 nm
Cross-track Spectral Error	<1.5 nm (VNIR), <2.5 nm (SWIR)
Spatial Co-registration	<20% of Pixel
Absolute Radiometric Accuracy	<6% (1 sigma)
Data Quantization	12-bit
Operability (SWIR, VNIR)	> 98% each*

Signal to Noise Ratio (SNR)

λ-range (μm)	SNR (min)
0.55-0.70	60
1.0-1.05	60
1.20-1.25	60
1.55-1.60	60
2.10-2.15	30

Modulation Transfer Function (MTF)

	VNIR MTF @ 8.33 l/mm			SWIR MTF @ 8.33 l/mm			
Wavelength (μm)	0.45	0.63	0.90	1.05	1.25	1.65	2.20
Minimum MTF Requirement	0.20	0.20	0.15	0.14	0.14	0.15	0.15

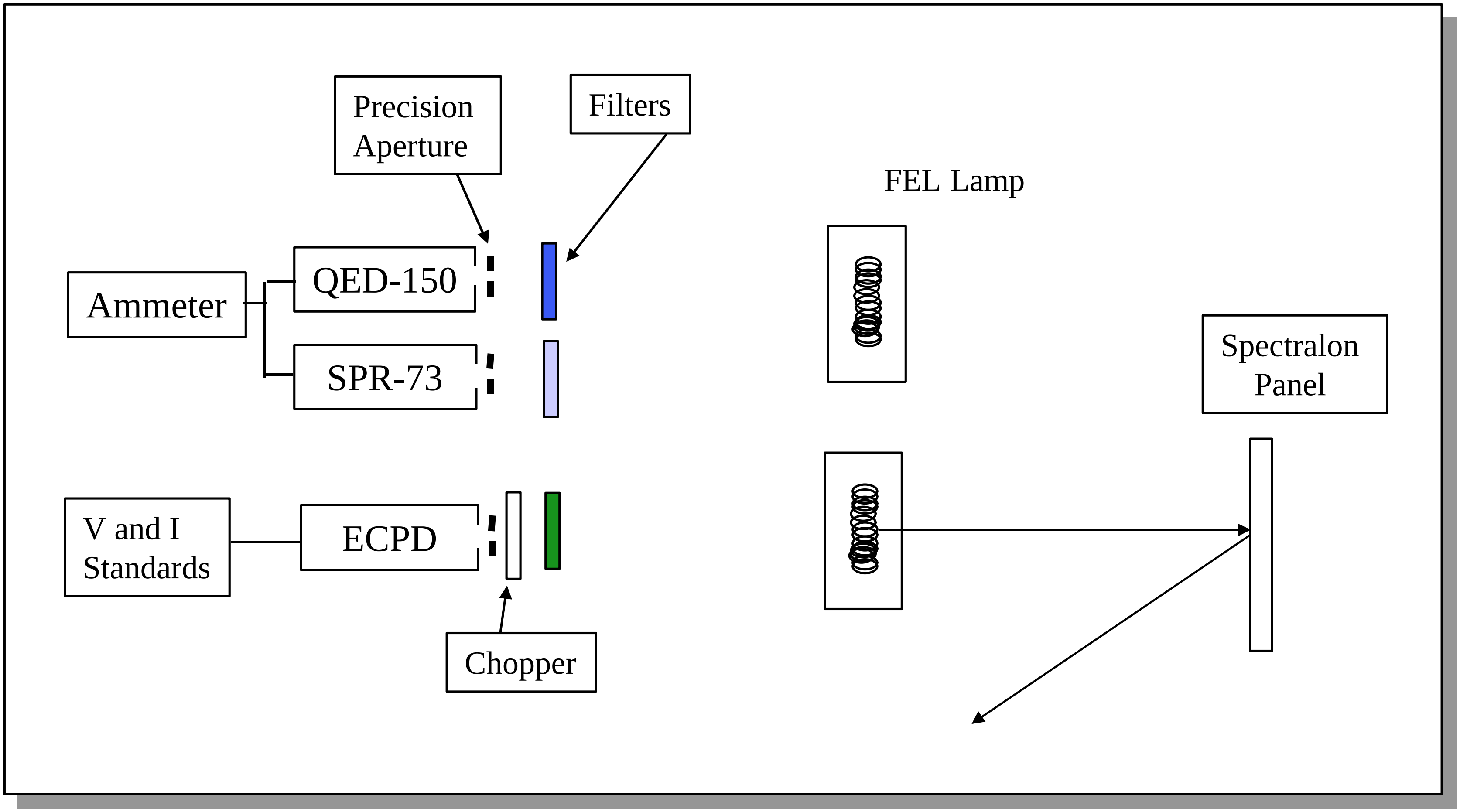
Hyperion Calibration/Characterization

. . . Peter Jarecke
Hyperion Calibration
TRW Space & Electronics

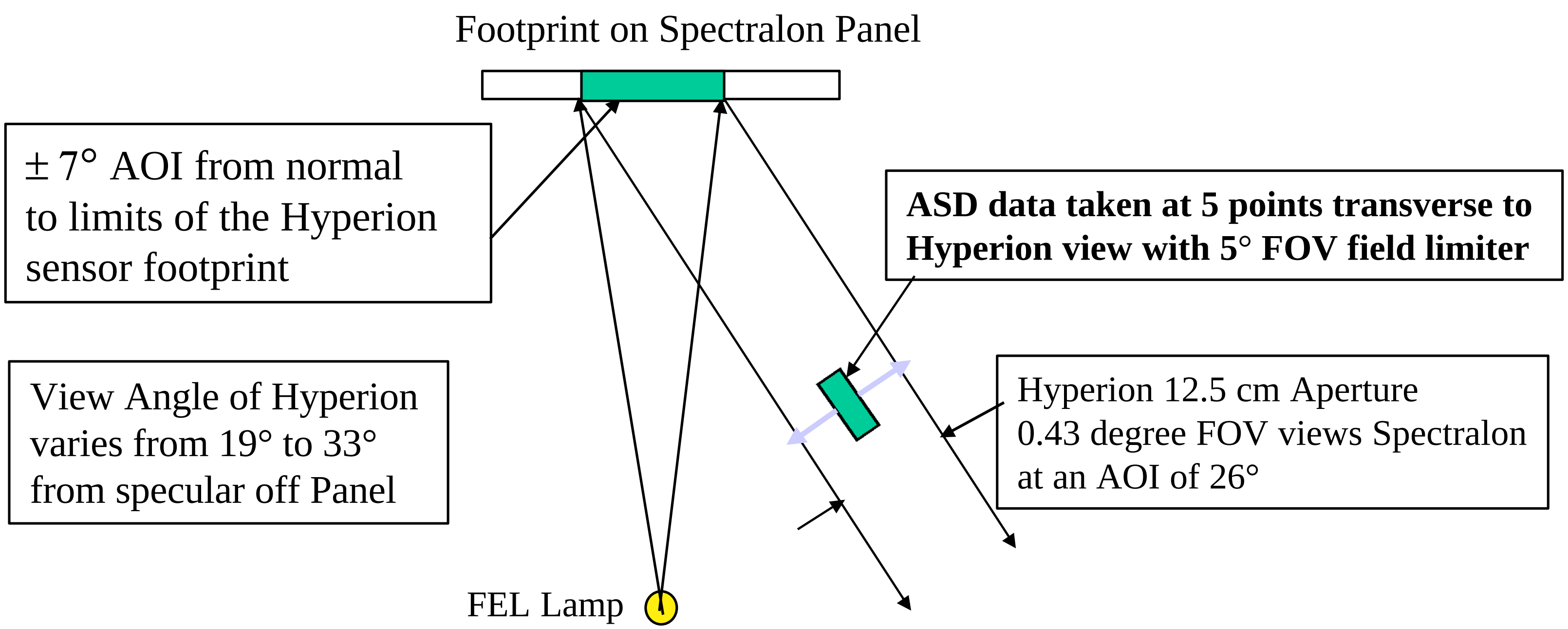
Radiometric Quantities To Be Characterized

- ***FPA Rectilinearity***
  - *Cross-Track Spectral Alignment (CTSA)*
  - *Spatial Co-Registration of Spectral Channels (SCSC)*
- ***Image Quality***
  - *Cross-track and Along-track MTF*
- ***Radiometric Responsivity - Calibration***
  - *Long Term Repeatablity*
- ***Pixel Center Wavelength Calibration***
- ***Signal to Noise***
- ***Ground Sample Distance and Swath Width***

Overview of Calibration Process



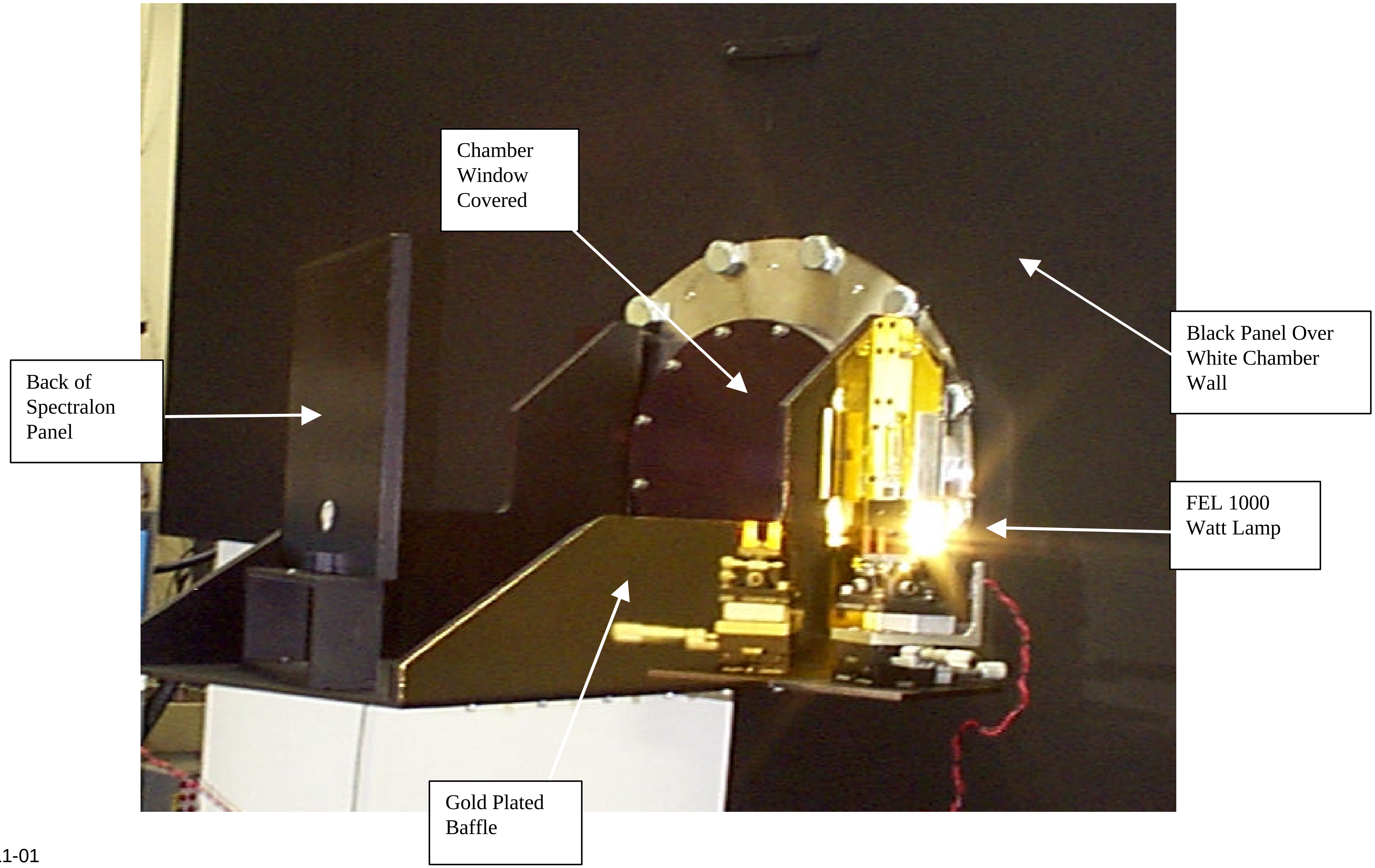
Conversion to Radiance



FEL Incident Irradiance falls as $\cos^3$ of the AOI which is a 2.5 % falloff in Irradiance

The BRDF characteristics of the Panel are critical in converting FEL Irradiance incident on the Panel to Radiance. The assumption that the BRDF is flat from 19° to 33° based on vendor data was tested using an ASD Field Spec as shown. ASD data matched the 2.5 % falloff to ± 0.3 %

Spectralon Panel Assembly Installed



Hyperion Radiometric Characterization Facility

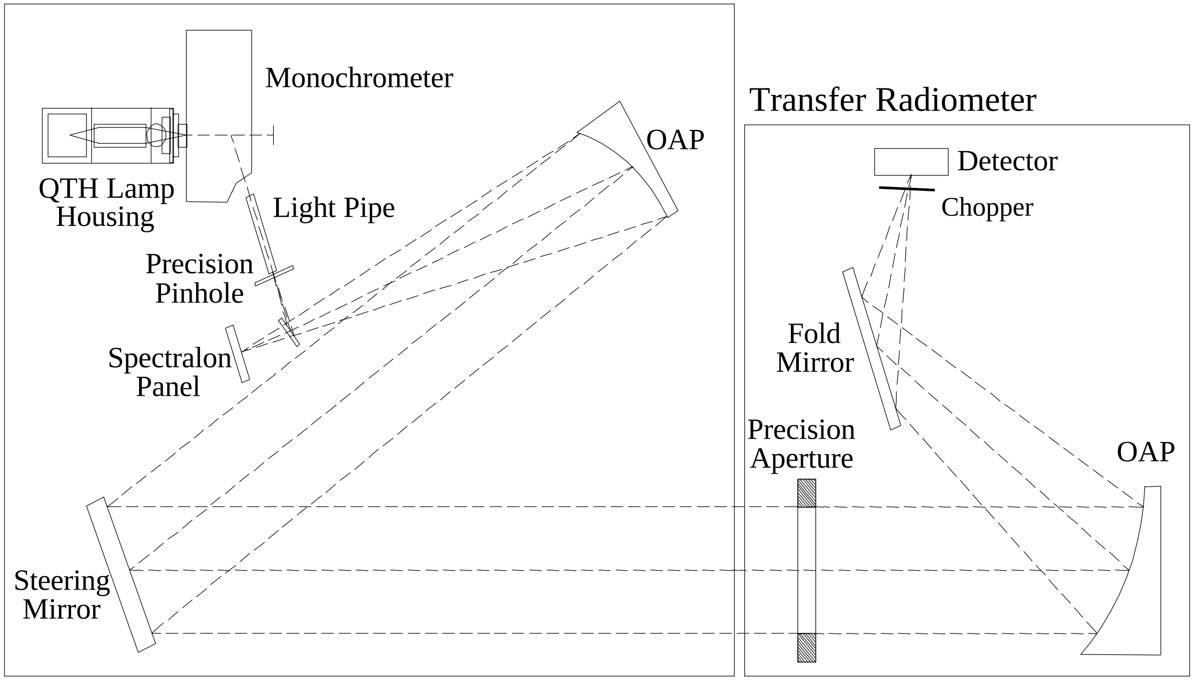
Formerly Known as the MSTB - Upgraded for
Hyperion Characterization

Two modes of Operation:

1) Pinhole, slit and/or Knife Edge at end of light pipe put at focus of OAP
2) End of light pipe is re-imaged onto Spectralon panel.

Both are shown simultaneously in chart without re-imaging optics

Steering mirror is a two axis, fine pointing mirror ($\pm$ 1–2 μrad) for sub-pixel scanning in spatial dimensions

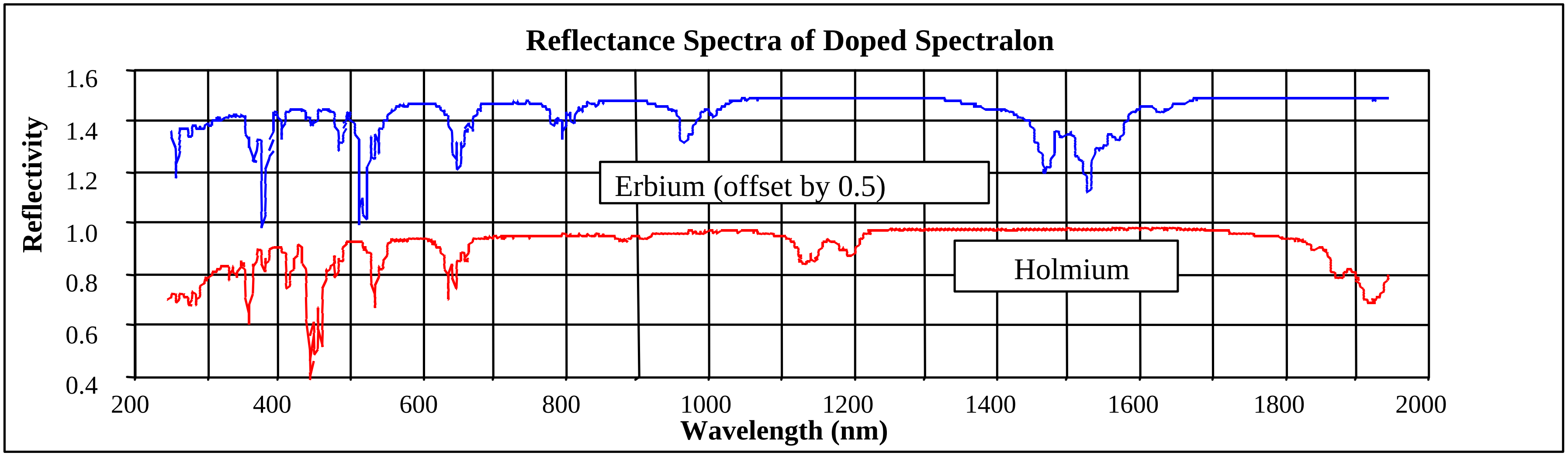


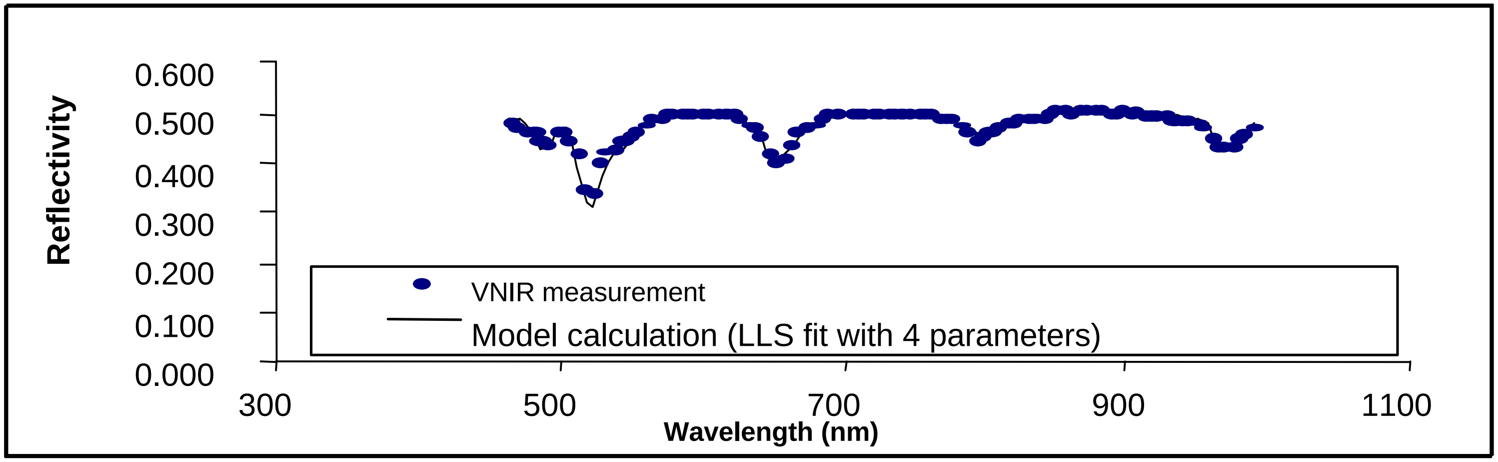
The transfer radiometer is a removable box for calibration of the Characterization Facility output.
It uses a chopped pyroelectric detector traceable to the TRW primary irradiance scale.
An accurate AΩ is calculated from precision apertures and OAP focal length.

Spectral Wavelength Calibration

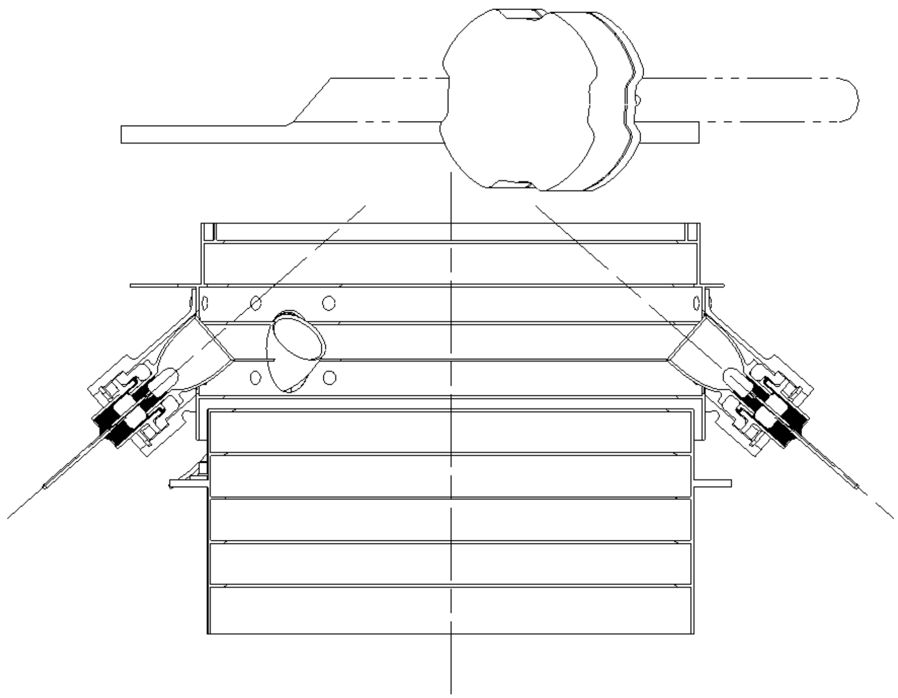
- ***High resolution scans of the Holmium and Erbium Oxide doped Spectralon are shown in the next chart.***
- ***Two sensor data frames are taken: one from a doped Spectralon panel and one from a high reflectance Spectralon panel.***
- ***The ratio of these two frames removes lamp illumination source wavelength variations and sensor response variations.***
- ***To derive a calculated curve for the above data, the high resolution scans are convolved with the sensor spectral response function. This degrades the high resolution scans to the lower sensor resolution.***
- ***A linear least squares (LLS) regression of the data points with the curve fixes the wavelength calibration of the sensor. Each spatial FOV position is calibrated in wavelength simultaneously for all spectral pixels saving time greatly.***
- ***The linear regression at each FOV position allows three constants for wavelength values at the pixel center (i.e. a second order fit in l versus pixel number). The width of the sensor pixel response function is also allowed to take on a best fit value for the LLS.***
- ***The accuracy of the fit is about 0.02 pixels (judgement call based on the width of the standard error minimum of the LLS fit)***

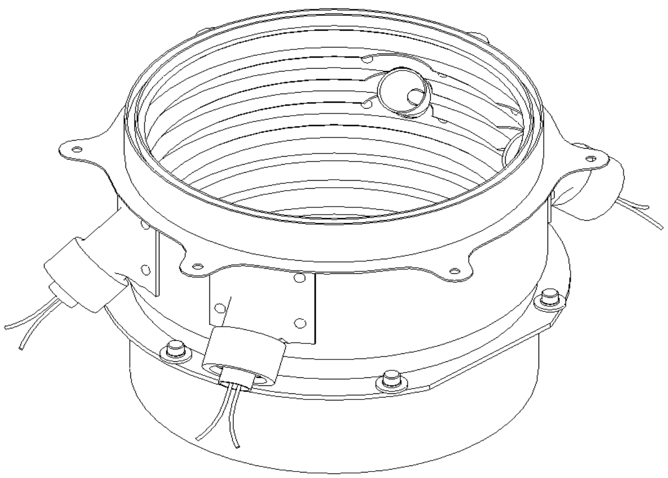
Spectral Wavelength Calibration

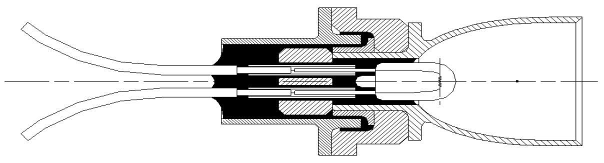




In-Flight Radiometric Calibration







On-Orbit Calibration Verification

Item	Req.	Ground	On-Orbit Approach
Absolute	< 6%	<6%	will combine solar calibration, lunar calibration, internal calibration and vicarious calibrations to address absolute calibration (refer to flow chart) models of sun and moon are required error budgets associated with vicarious calibration required
Linearity		linear (~1%)	will assume linear and verify (if possible) using results of the absolute calibration events
Calibration Source Stability			calibration lamp image obtained with each DCE and performance of the lamp will be trended absolute measure of lamp radiance will be performed when making absolute measurements described above results compared with calibration values and suspected drift

Radiometric Long Term Monitoring Plan

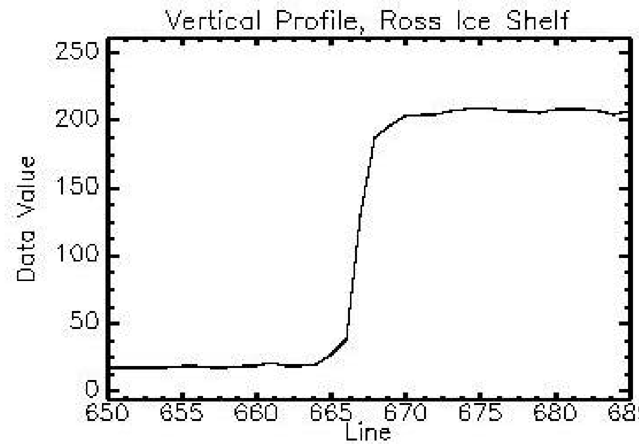
Item	On-Orbit Approach
Stability	scenes identified as being repeatable will be obtained multiple times and compared: Saharan, TBR sites selected for vicarious calibration can also be used especially if obtained multiple times response from calibration lamps will be trended
Temperature Sensitivity	VNIR: ASP temperature controlled, FPE temperature sensitivity will be established SWIR: ASP temperature could be controlled, FPE temperature is controlled by the cryocooler orbital temperature variations will be trended
Flatfield (streaks)	use internal calibration lamp to adjust for time of scene gain changes if present

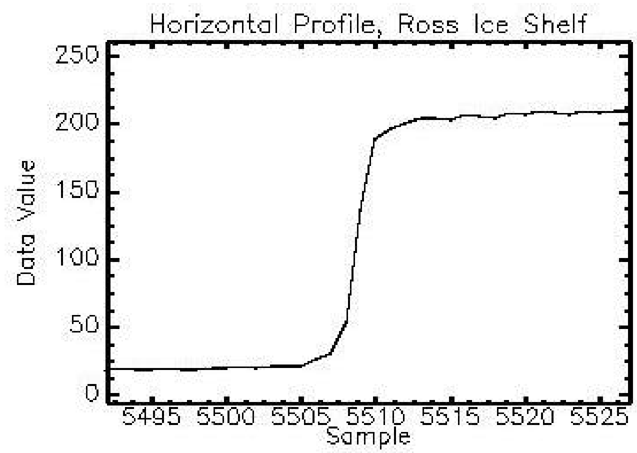
Image Quality

Item	Req.	Ground	On-Orbit Approach
GSD	30 m ±1m	29.88 m	Use scenes that contain objects with known separation distance, need ground truth of scene potentially use digital images: Cities ex: El Segundo, Active Illumination determine pixel distance between centroid of independent features need multiple measurements to de-couple cross track and along track distance
Swath Width	> 7.5 km	> 7.5 km (7.65 km)	Extension of cross track GSD and number of used FOV pixels
Swath Length		160 km based on 24 second DCE	Extension of along track GSD and length of DCE

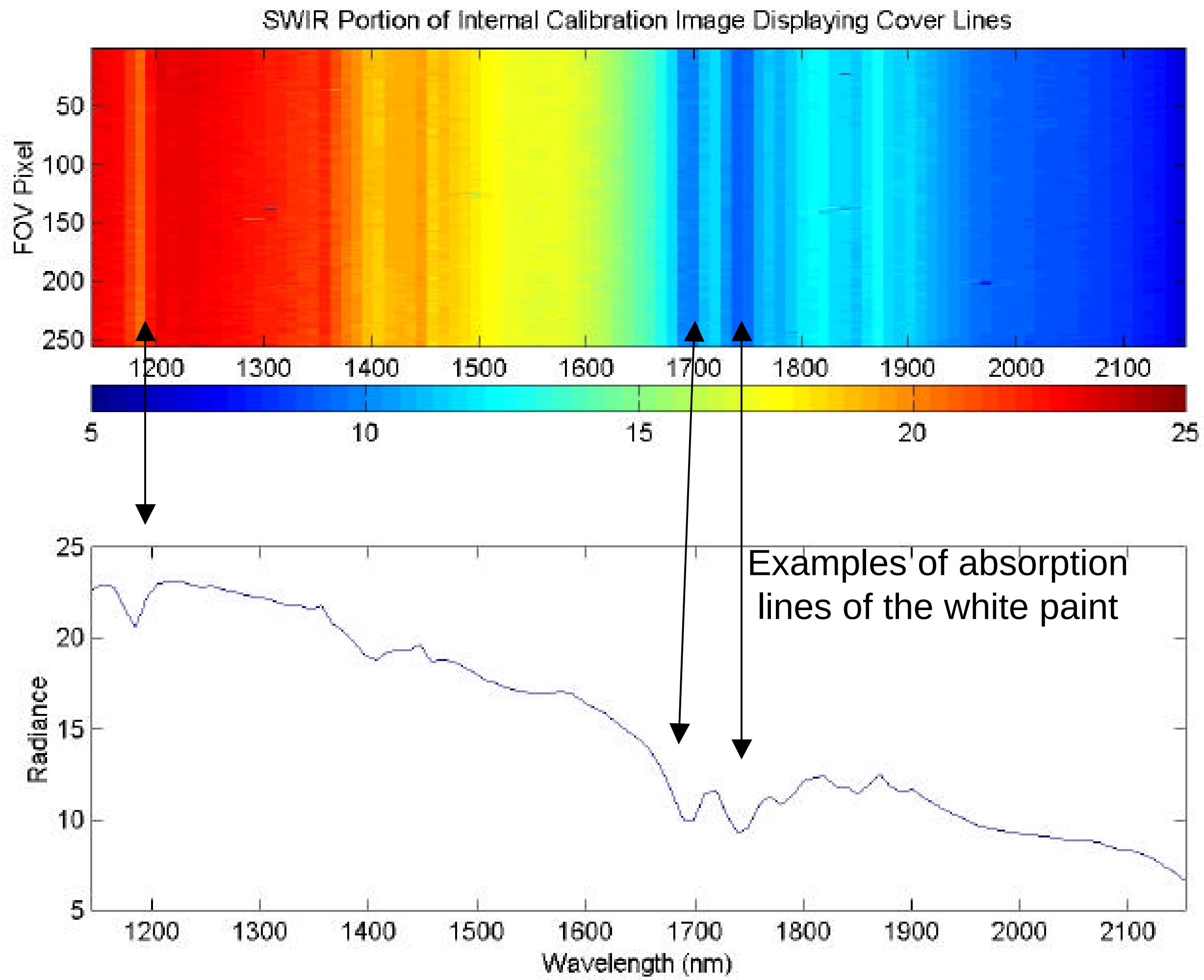
Image Quality Example

Vertical and Horizontal MTF can be calculated from diagonal edge





Spectral Calibration Using Internal Calibration System



Hyperion Flight Validation

. . . Dr. Carol Segal
Hyperion Deputy Project Manager, Mission Operations
TRW Space & Electronics

Hyperion Performance Verification

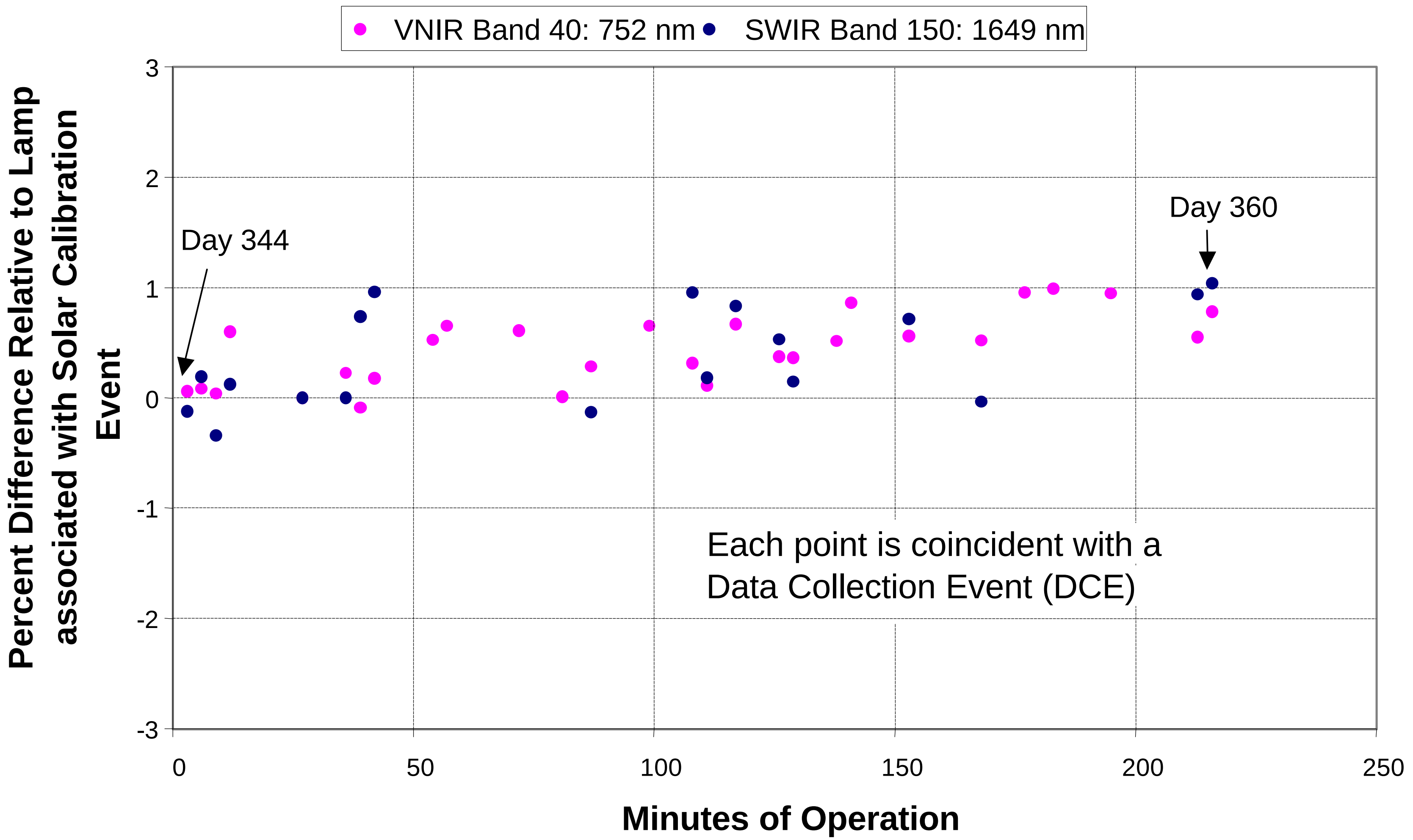
- ***The On-orbit Performance Verification Plan was completed in preparation for the on-orbit 60 day checkout period:***

Phase	Description	Day	Function
1	Initial VNIR Turn On	6	Perform Instrument Functional Tests
2	Heated Outgassing	7-17	Monitor Trended Parameters VNIR Internal Calibration Assess Processing Turn-around time VNIR Earth Image Collection
3	Instrument Verification Assess Readiness for Characterization	18-30	Cryocooler Operational – SWIR Turn-on SWIR Internal Calibration VNIR SWIR Earth Image Collection
4	Instrument Characterzation Calibration	18-60	Assess Instrument Performance Initialize Long Term Characterization

Hyperion Activation

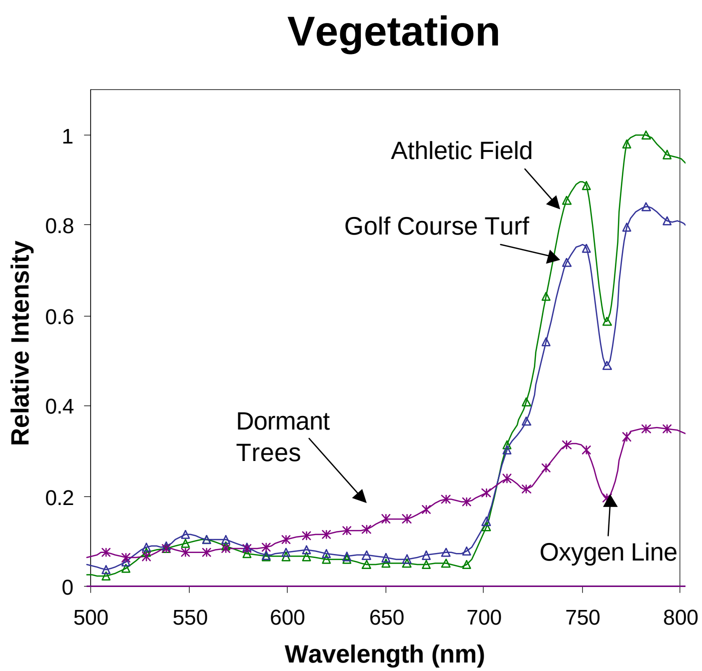
Instrument Subsystem	Activation Date/Time	Current Status
HEA	27 Nov 00, GMT=332:1232	(phe-)**NOMINAL**
Analog Signal Processors	27 Nov 00, GMT=332:1410	(phe-)**NOMINAL**
Heaters	27 Nov 00, GMT=332:1600 – all heaters cycling @ nominal temps	(phe-)**NOMINAL**
Internal Calibration Lamps	27 Nov 00, GMT=332:1427	(phe-)**NOMINAL**
Aperture Cover	27 Nov 00, GMT=332:1915	(phe-)**NOMINAL**
VNIR Focal Plane (1st image)	27 Nov 00, GMT=332:1601 – internal cal 28 Nov 00, GMT=333:0526 -- ground	(phe-)**NOMINAL**
Cryocooler	29 Nov 00, GMT=334:1716 – functional test 8 Dec 00, GMT=343:1426 – 1st cooldown	(phe-)**NOMINAL**
SWIR Focal Plane (1st SWIR image)	8 Dec 00, GMT=343:1921 – internal cal 8 Dec 00, GMT=344:0030 -- ground	(phe-)**NOMINAL**

On-Orbit Repeatability of Calibration Lamp

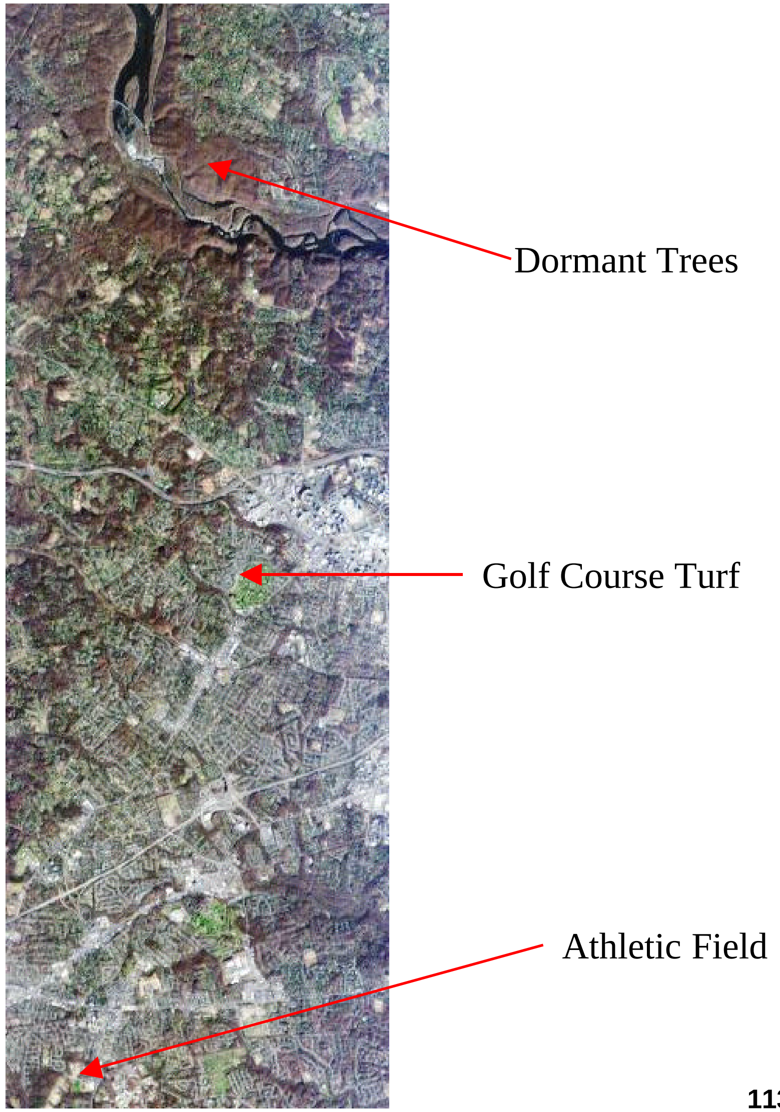


Hyperion Image of Fairfax, VA December 2000

Image taken by Hyperion shows the relative chlorophyll content of vegetation in Fairfax County. The spectral profiles indicate healthy grass in the athletic field and golf course. The spectral profile of the trees indicates dormant vegetation.



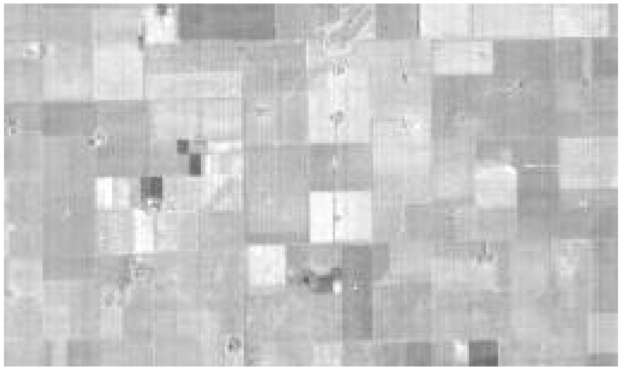
Oxygen in the atmosphere is detected by the spectral profiles in the near infrared wavelength.



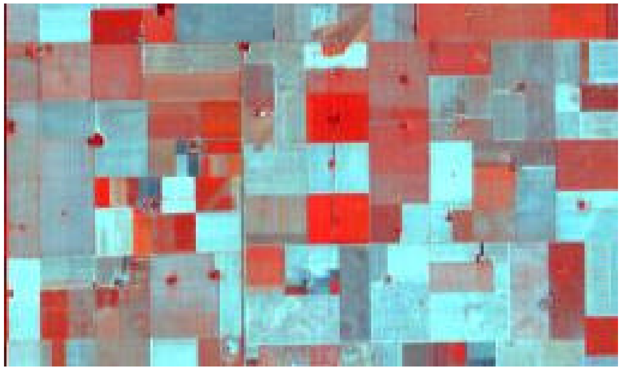
Verrazano-Narrows Bridge, New York

Geometric: Example

VNIR Band 30: ~650 nm



SWIR Band 85: ~993nm

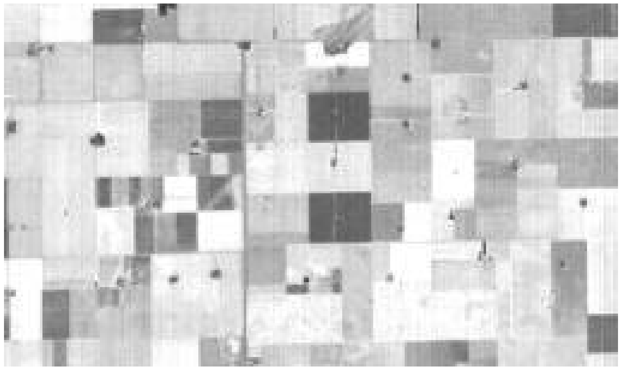


Cordoba Soybean

False RGB, Red is healthy vegetation: 51,23,16

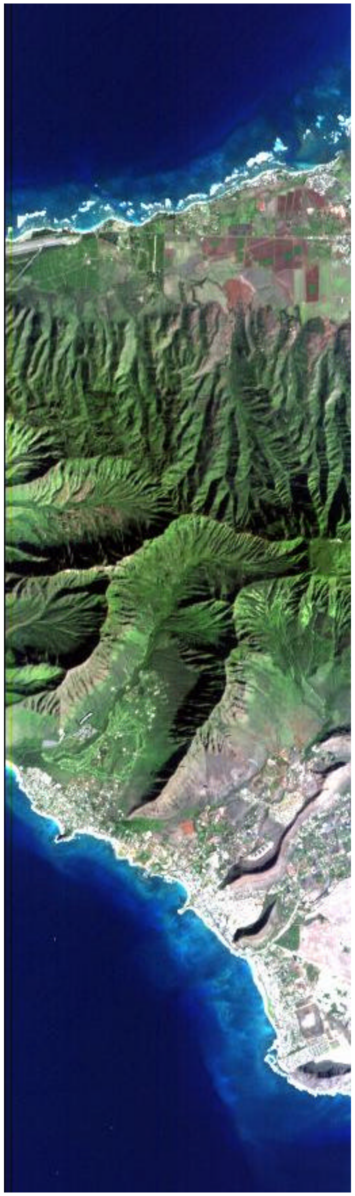
~(864,578,507 nm)

VNIR Band 40: ~752 nm



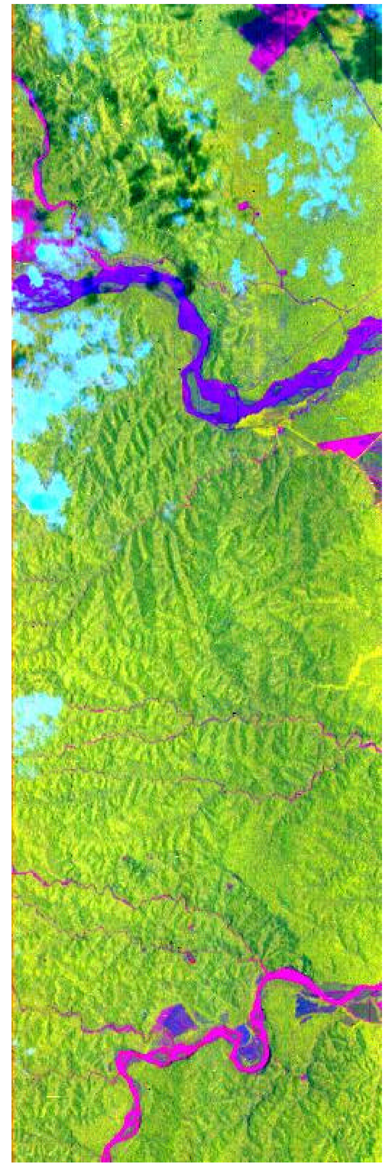
SWIR Band 150: ~1649 nm

Oahu, HI



Tariquia, Bolivia

Visible RGB



False RGB Representing Pixel Purity